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REPORT

MAP PROJECTIONS FOR PLANNING OF BROADCASTING SERVICES:
use of a digital computer

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MAP PROJECTIONS FOR PLANNING OF BROADCASTING SERVICES: USE OF A DIGITAL COMPUTER

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Summary

Facilities for map production using a digital computer have recently been developed. The use of a computer allows the choice of scale and projection, so that individual maps may be designed to satisfy specific requirements. This Report provides examples of these maps and describes their uses in the planning of broadcasting services.

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MAP PROJECTIONS FOR PLANNING OF BROADCASTING SERVICES: USE OF A DIGITAL COMPUTER

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1. Introduction

Maps are essential for planning of broadcasting services but existing maps are often unsatisfactory for this purpose. If a map of a specific area is required, it seems almost inevitable that the available maps will be unsuitable either because they do not cover the whole of the required area or because they use inconvenient scales or projections. The scale of a map may be altered by photographic techniques, but it is generally impractical to modify the projection.

The introduction of computer facilities for production of maps enables the user to specify the scale and projection required for each map. The ability to choose the most suitable projection is particularly valuable, allowing maps to be designed to satisfy specific requirements.

This Report shows some examples of the maps produced and describes their applications for planning of broadcasting services.

2. Computer facilities

The computer programmes have been written in FORTRAN V for use with a Univac 1108 computer. A number of standard projections are readily available in the programme and new projections may be added as required.

The coastlines and national boundaries are stored as a series of geographical co-ordinates, in sufficient detail for maps whose scales do not exceed 1/3,000,000. These co-ordinates are converted into cartesian co-ordinates, as defined by the map projection, for output on an automatic plotter.

To obtain a map, the following input data is required:

(i) the type of projection – at present the following are available in the programme library: azimuthal equi-distant, azimuthal equal-area, Bonne equal-area, conical equi-distant, conical equal area (oblique), Mercator and 'satellite' projections.

(ii) the parameters of the projection – for example, the co-ordinates of the origin for azimuthal projections or the standard parallels for conical projections.

(iii) the scale of the map.

(iv) the limits of the area to be shown on the map – these are defined by lines of latitude or longitude.

Additional facilities include plotting of:

(i) lines of latitude and longitude at specified intervals;

(ii) locations and names of towns or transmitting stations;

(iii) contours of magnetic variation and magnetic dip;

(iv) great circles between two specified locations;

(v) field strength contours of radio transmissions (in conjunction with computer programmes to calculate the geographical co-ordinates of the contours).

The maps shown in Figs. 2–5, which were originally plotted at a scale of 1/50,000,000 each used about 60 seconds of central processor time. The running time depends on the size of the map, on the number of geographical co-ordinates to be converted and the number of lines of latitude and longitude to be plotted.

3. Azimuthal equi-distant projections

An azimuthal equi-distant map is constructed so that great circle distances and bearings from the origin of the map are correctly represented. Fig. 1 shows an azimuthal equi-distant map with its origin at Sydney. The distortion of the map increases with distance from the origin, and it will be appreciated that measurements of distance or bearing on this type of projection are accurate only from the map origin.

Azimuthal equi-distant maps are particularly useful if the origin of the map is coincident with a radio transmitting or receiving station. Several maps of this type have been produced for use by BBC external services.

4. Equal-area projections

The area of a zone on an equal-area map projection is directly proportional to the area of the zone on the surface of the earth. This is achieved by distortion of the map scale: for any point on the map the scale distortion in a given direction is arranged to be the reciprocal of the scale distortion in the orthogonal direction, thus achieving correct representation of areas.

The equal-area property is useful for general purpose maps. In radio planning at medium frequencies, it has often been suggested that use of a linear lattice network of transmitters would offer significant advantages. In a uniform plane lattice network, transmitters are evenly distributed in terms of area and interference levels are the same for each transmitter. The lattice must however be distorted to fit the curved surface of the earth and this distortion generally destroys the uniform nature of the network. One approach to this problem is to superimpose a plane lattice network on an equal-area map. The resulting lattice network on the earth's surface will automatically have uniform distribution of transmitters. If the scale distortion on the map is small, the distances between transmitters will be close to the nominal distances on the plane lattice network, and the resulting interference levels will be almost uniform.

It is, however, difficult to achieve low scale distortion over a large area of the earth's surface. This is illustrated by the equal-area projections of Europe, Africa, Asia and Australasia in Figs. 2 and 3.

The Bonne projection in Fig. 2 gives accurate representation along the standard parallel 30°N and along the central meridian 75°E. There is however considerable distortion of north-western Europe, eastern parts of the USSR, of southern parts of Africa and of Australia and New Zealand. The representation of Australia and New Zealand may be compared with that shown in Fig. 1.

The distortion in the azimuthal equal-area projection in Fig. 3 increases with distance from the origin of the map, 30°N 75°E. It is slightly less than that of the Bonne projection over most of the map, but there is significant distortion of southern and western parts of Africa, and of Australia and New Zealand.

Figs. 2 and 3 show the difficulty of producing a satisfactory map of this area using the most common types of equal-area projections. Both maps give good representation of central Asia but poorer representation of the more distant land masses.

A different type of projection, known as an oblique conical equal-area projection, has been devised to achieve better representation of this area; an example is shown in Fig. 4. The parameters of this projection have been chosen to minimise distortion of the land areas; the scale distortion is less than 10% over most of the land areas, compared with distortion of up to 50% or more with the other projections. There is, however, considerable distortion near the 'pole' of the map at 15°S, 75°E and it is obvious, from the shape of the map that it should not be used for measurements across the Indian Ocean.

5. Minimum bearing-error projection

Recent methods[1,2] for prediction of sky-wave field strengths at medium frequencies have included calculation of polarisation coupling loss for transmission paths with one or both terminals in the tropical zone (for this purpose, between approximately 30°N and 10°S). This calculation requires the knowledge of the bearing of the great circle path from each terminal. The required accuracy of this bearing is highest for east-west paths and for terminals close to the magnetic dip equator (which corresponds to approximately 10°N in Africa and Asia). A projection has been designed from which bearings may be measured to within 2° for path lengths of up to 4000 km from terminals at 10°N; the accuracy of measured bearings in the critical east-west direction is even better. The error increases for terminals away from 10°N, where less accuracy is required. An example of this projection is shown in Fig. 5. The projection is basically a conical projection with two standard parallels at 28·6°N and 9·4°S, but modifications have been made to improve the accuracy with which distances can be measured from the map; measured distances are within 3% of their true values for paths of up to 5000 km from terminals at 10°N.

6. Field-strength maps

A natural extension of computer facilities for map production is to automatically plot field-strength contours on the maps. Contour plotting sub-routines are available and an example of their use is shown in Fig. 6. This map uses an azimuthal equi-distant projection centred on the m.f. station at Masirah. Sky-wave field strengths for a transmitter on 1410 kHz at Masirah have been calculated by a method adopted by the Regional Administrative LF/MF Broadcasting Conference,[2] and contours have been plotted at 5 dB intervals.

To illustrate the versatility of map production by computer, a novel projection has been devised to show field-strengths from a given transmitter. Instead of plotting the field strength contours on a normal map as in Fig. 6, the map may be distorted so that the field strength contours are circular. The position of each point on the map relative to the transmitter is determined by the sky-wave field strength at that point and its great circle bearing from the transmitter. An example of this type of projection is shown in Fig. 7 for a transmitter on 1214 kHz at Droitwich. The discontinuities in parallels and meridians derive from discontinuities inherent in the agreed method of calculating field strength.

7. Maps for satellite broadcasting

For broadcasting from a geo-stationary satellite, the calculation of service area boundaries is complicated by the fact that the shape of the boundary on the earth's surface is generally different from the cross-section of the beam of the transmitting aerial. Even with the simplest case of a conical beam, the shape of the service area is dependent on the location of the service area relative to the sub-satellite point. If the parameters of the transmitting aerial, such as the location of the aiming point and the shape of the beam, are known it is simple to calculate the service area boundaries. It is, however, more difficult to determine the transmitting aerial parameters required for coverage of a specified area.

A simple sollution to this problem is to produce a map which is distorted so that the dimensions of the service area shown on the map are proportional to the dimensions of the transmitting aerial beam. For example, if a conical beam is aimed at some point on the surface of the earth, the resulting service area should be shown on the map as a circle of appropriate radius centred on the aiming point. To achieve this result, the distance between any two points on the map must be proportional to the angular separation of the two points on the earth's surface as observed from the satellite. It is not possible to satisfy this requirement exactly, but a projection has been devised for which the maximum error in measurements of angular separation is less than 0·4%. This error may be neglected as the transmitting aerial characteristics are not known to such accuracy.

Fig. 8 shows a map of Europe using this projection for a satellite position of 30°W. This map could be used to choose the transmitting aerial characteristics required to provide coverage of a specified area from this satellite position.

If transparent overlays of transmitting aerial patterns were superimposed on these maps, it would be possible to obtain directly values of transmitting aerial directivity between the aiming point of the beam and any other point on the map.

8. Conclusions

Facilities for map production using a digital computer have recently been introduced. The use of a computer allows the choice of scale and projection, so that individual maps may be designed to satisfy specific requirements. The report provides some examples of map projections which are useful in the planning of broadcasting services.

An azimuthal equi-distant projection is constructed so that great circle distances and bearings from the origin of the projection are correctly represented. This is particularly useful if maps are produced with the origin at a radio transmitting or receiving stations.

Equal-area map projections could be used to fit a plane lattice network of transmitters on to the curved surface of the earth without seriously affecting the uniform distribution of transmitters or uniform levels of interference.

Calculation of polarisation coupling loss at medium frequencies requires knowledge of great circle bearings from terminals near the magnetic dip equator. A map has been produced from which measured bearings are sufficiently accurate for this purpose.

Maps have also been produced to facilitate choice of transmitting aerial parameters for a geo-stationary satellite to obtain coverage of a specified area.

The computer may be used to calculate the value of any variable which is a mathematically definable function of latitude and longitude; the results may be plotted directly on to a map as a series of contours. This technique is used to produce maps showing sky-wave field strength contours of medium frequency transmissions.

These techniques of map production will obviously have widespread application in planning of broadcasting services and in other types of work.

9. References

1. Methods of predicting sky-wave field strengths as frequencies between 150 kHz and 1600 kHz. CCIR Report 575, 1974.

2. Report of First Session of ITU Broadcasting Conference. Geneva 1974.

Appendix

Map Projection Equations

Each projection is defined by a set of equations, which convert the latitude μ and longitude λ of any point on the surface of the sphere into two-dimensional coordinates (x, y). r is the scaled radius of the earth.

(i) Azimuthal Equi-Distant
Origin at latitude μ_o longitude λ_o
$x = r\beta \sin\theta \quad : \quad y = r\beta\cos\theta$
where $\cos\beta = \sin\mu \sin\mu_o + \cos\mu\cos\mu_o\cos(\lambda - \lambda_o)$
$\cos\theta = (\sin\mu - \sin\mu_o\cos\beta)/\cos\mu_o\sin\beta$
θ has the sign of $\sin(\lambda - \lambda_o)$

(ii) Azimuthal Equal-Area
Origin at latitude μ_o longitude λ_o
$x = 2r\sin(\beta/2)\sin\theta \; , \; y = 2r\sin(\beta/2)\cos\theta$
where $\cos\beta = \sin\mu\sin\mu_o + \cos\mu\cos\mu_o\cos(\lambda - \lambda_o)$
$\cos\theta = (\sin\mu - \sin\mu_o\cos\beta)/\cos\mu_o\sin\beta$
θ has the sign of $\sin(\lambda - \lambda_o)$

(iii) Bonne Equal-Area
μ_o is the standard parallel
λ_o is the central meridian
$x = r[\cot\mu_o - (\mu - \mu_o)]\sin\theta,$
$y = r[\cot\mu_o(1 - \cos\theta) + (\mu - \mu_o)\cos\theta]$
where $\theta = \cos\mu(\lambda - \lambda_o)/[\cot\mu_o - (\mu - \mu_o)]$

(iv) Conical Projection with Two Standard Parallels
μ_1, μ_2 are the standard parallels
λ_o is the central meridian
$x = r \, . \, p\sin\theta \; , \; y = r(p_o - p\cos\theta)$
where $p_o = (\mu_2 - \mu_1)\cos\mu_2/(\cos\mu_1 - \cos\mu_2)$
$p = p_o - (\mu - \mu_2)$
$\theta = (\lambda - \lambda_o)\cos\mu_2/p_o$

(v) Oblique Conical Equal-Area
'Pole' at latitude μ_o longitude λ_o
μ_1, μ_2 are the standard 'oblique parallels'
$x = r\,p\sin\alpha \; , \; y = r\,p\cos\alpha$
where
$p = \sqrt{p_o^2 + 4(\sin\mu_1 - \cos\beta)/(\sin\mu_1 + \sin\mu_2)}$
$p_o = 2\cos\mu_1/(\sin\mu_1 + \sin\mu_2)$

$\alpha \;= \theta(\sin\mu_1 + \sin\mu_2)/2$
$\cos\beta \;= \sin\mu_0 \sin\mu + \cos\mu_0 \cos\mu \cos(\lambda - \lambda_0)$
$\cos\theta \;= (\sin\mu - \sin\mu_0 \cos\beta)/\cos\mu_0 \sin\beta$
θ has the sign of $\sin(\lambda - \lambda_0)$

(vi) Mercator
The meridian (λ_0) is the western limit, the parallel (μ_0) is the southern limit.
$x = r(\lambda - \lambda_0)$, $y = r \log_e(\sec\mu + \tan\mu) - y_0$
where $y_0 = r \log_e(\sec\mu_0 + \tan\mu_0)$

(vii) 'Satellite' Projection
$x = r\,\alpha \sin\theta$, $y = r\,\alpha \cos\theta$
where $\tan\alpha = \sin\beta/(6{\cdot}62 - \cos\beta)$
$\cos\beta = \cos\mu \cos(\lambda - \lambda_0)$
$\cos\theta = \sin\mu \sin\beta$
θ has the sign of $\sin(\lambda - \lambda_0)$

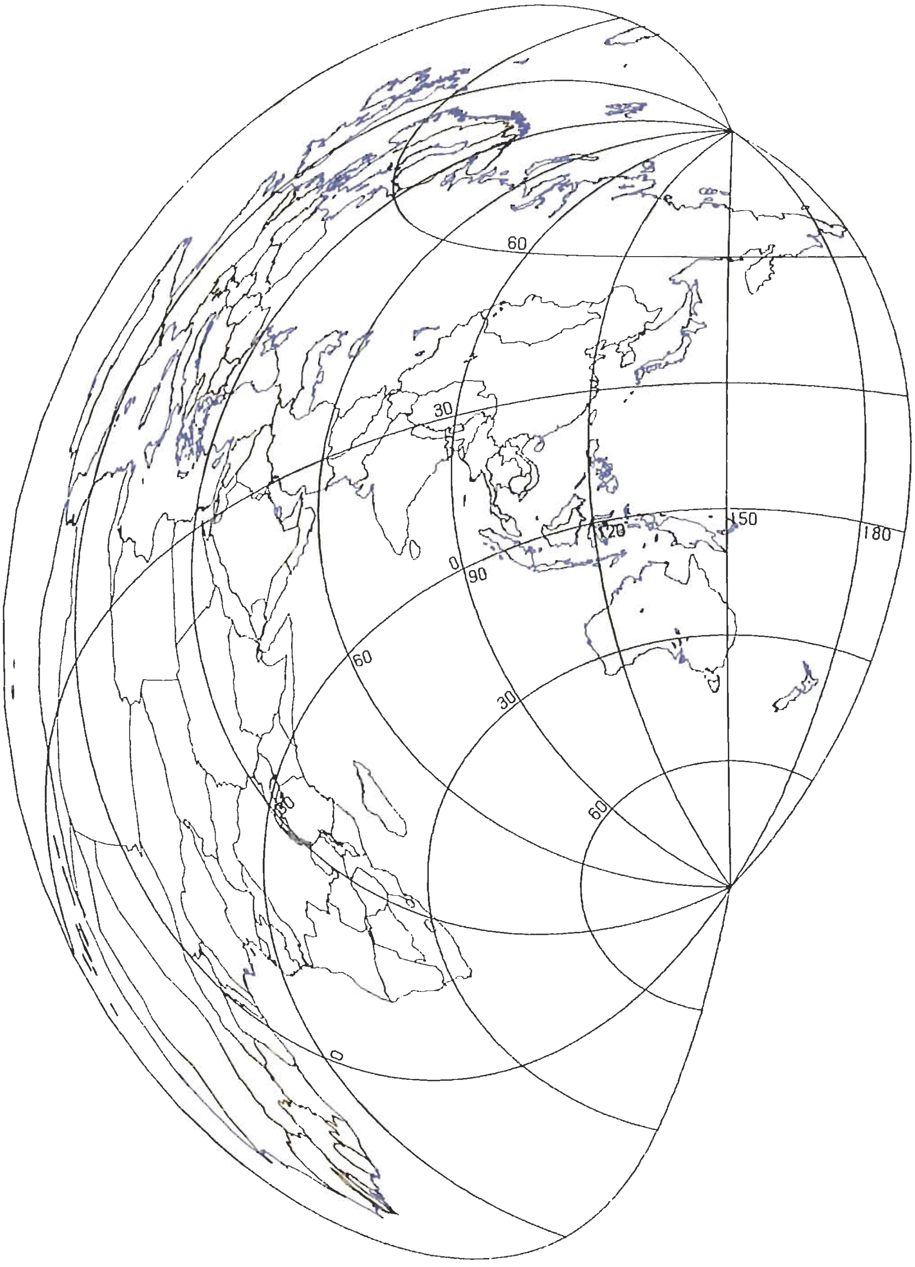


Fig. 1 - Azimuthal equi-distant projection
Origin: 34°S, 151°E
Scale: 1/200,000,000

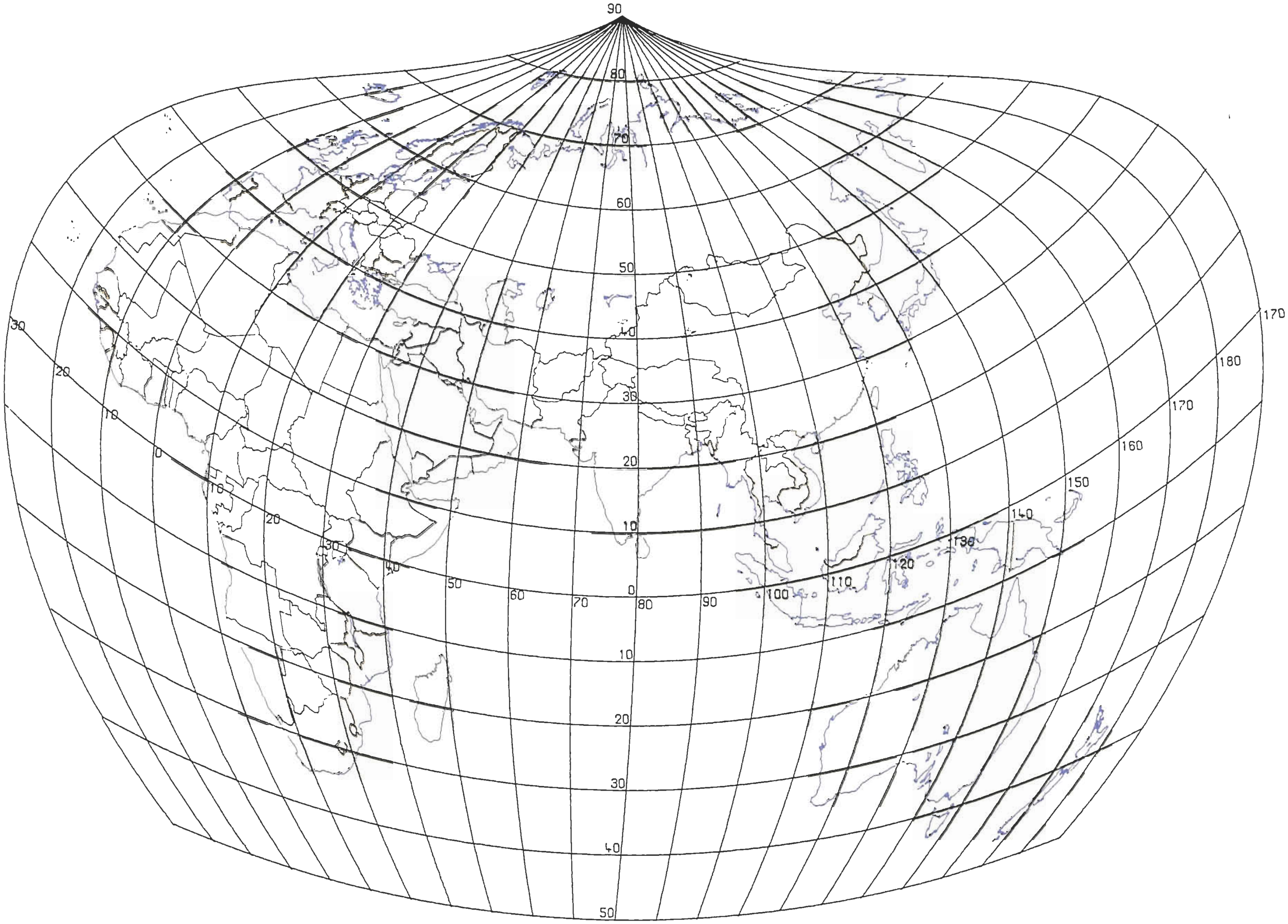


Fig. 2 - Bonne equal-area projection

Standard parallel 30°N Central meridian 75°E

Scale: 1/100,000,000

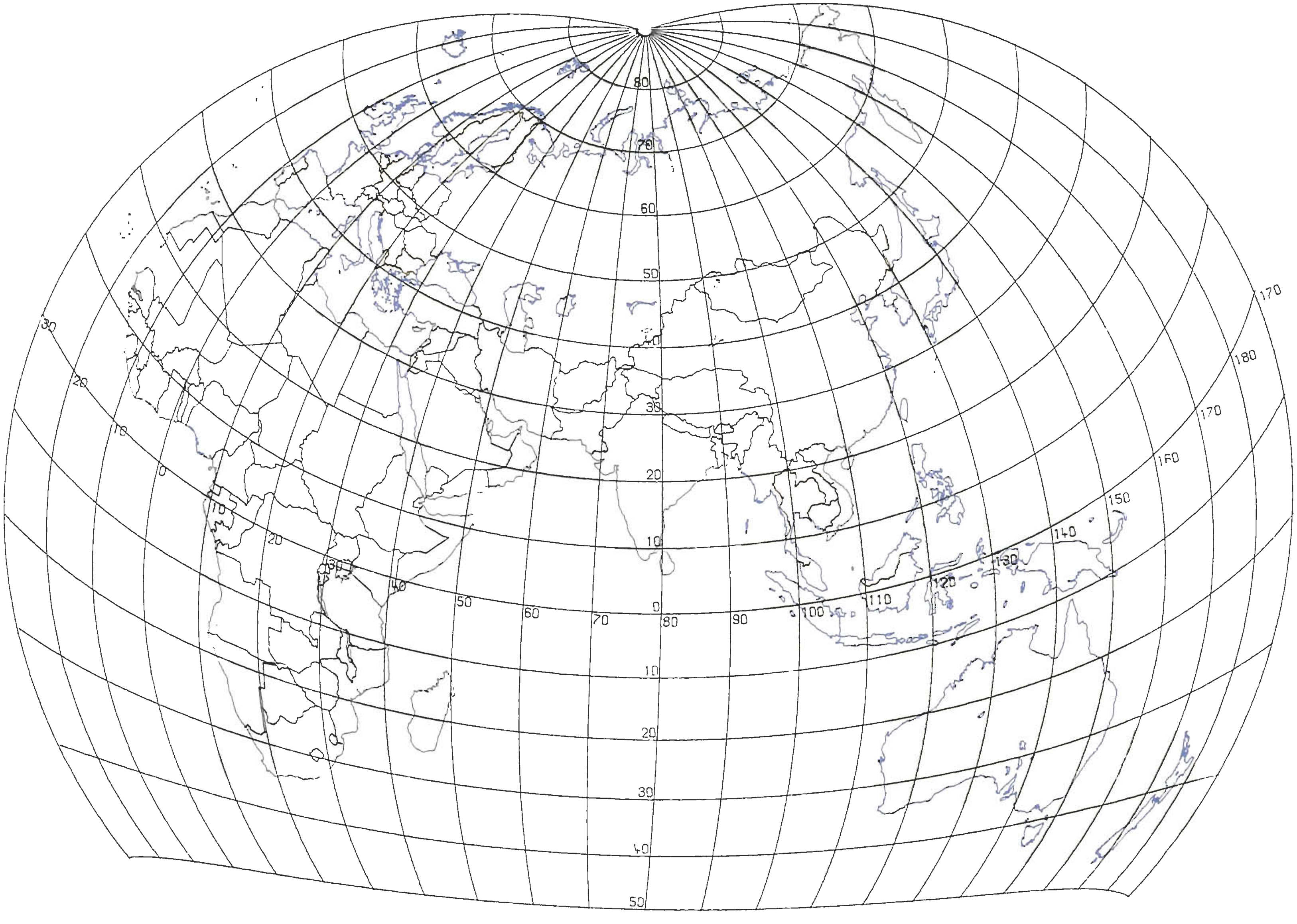


Fig. 3 - Azimuthal equal-area projection
Origin: 30°N, 75°E
Scale: 1/100,000,000

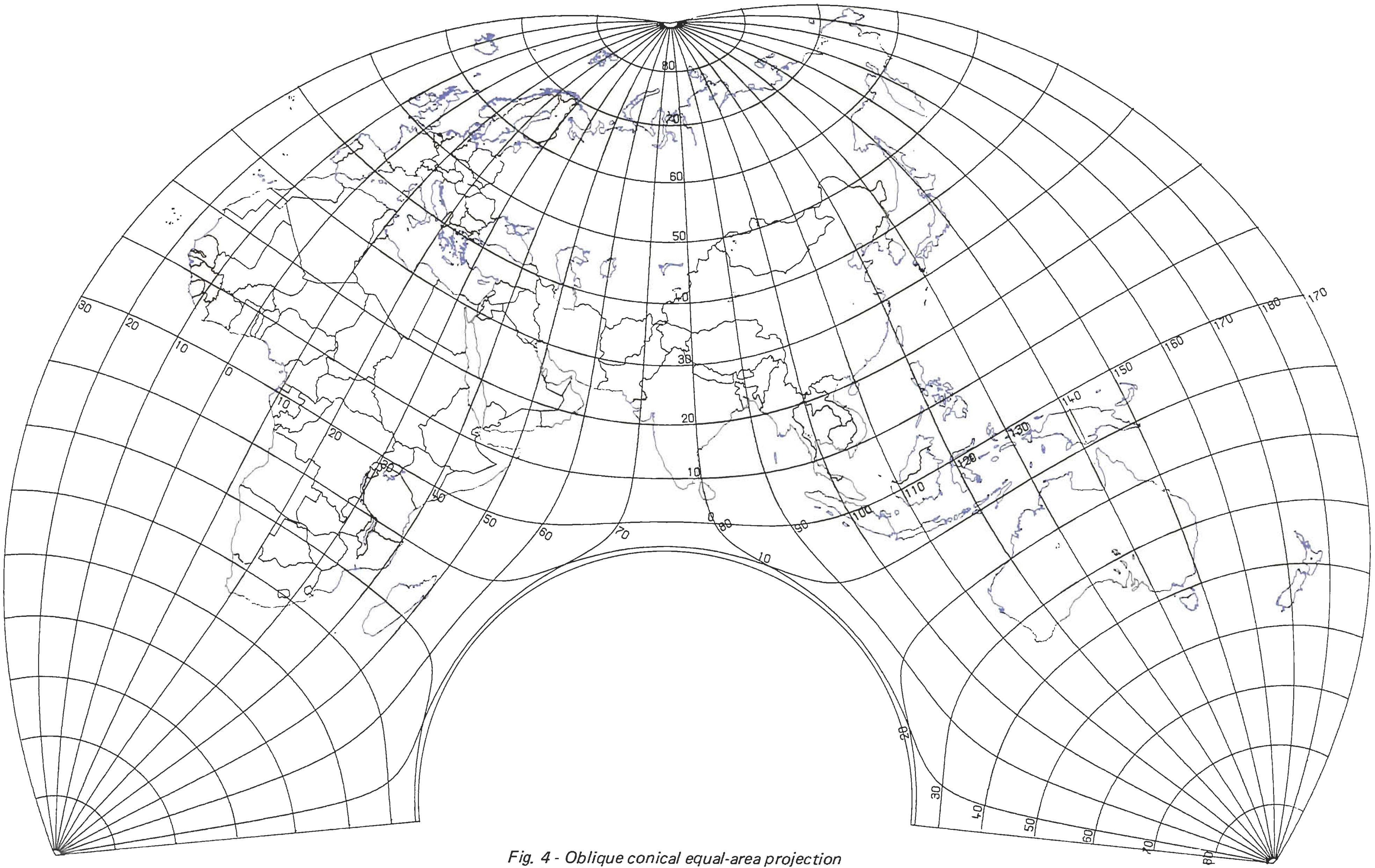


Fig. 4 - Oblique conical equal-area projection
Pole: 15°S, 75°E Standard oblique parallels: 52°, 16°
Scale: 1/100,000,000

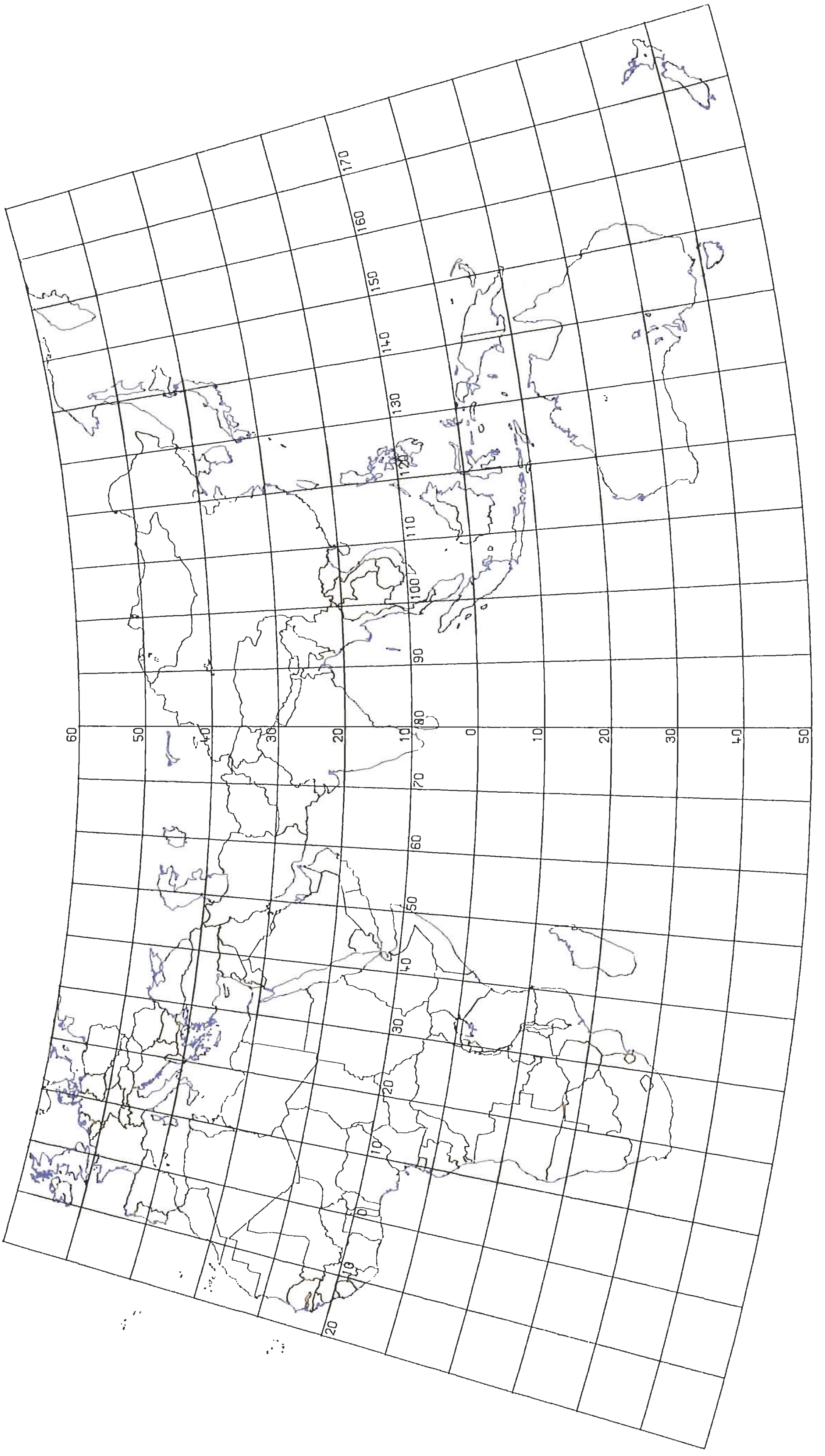


Fig. 5 - Conical projection
Standard parallels: 28·6°N 9·4°S
Scale: 1/100,000,000

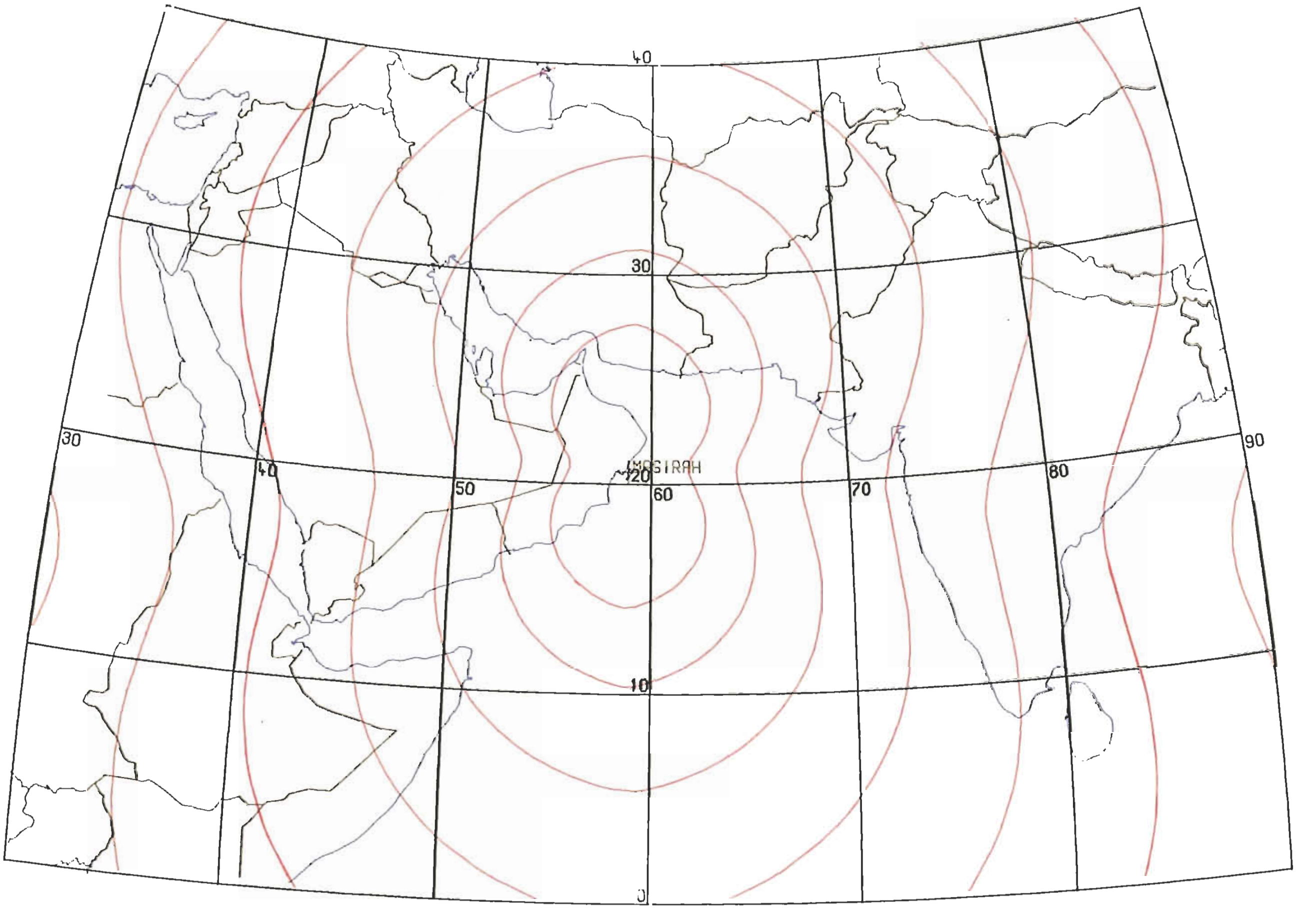
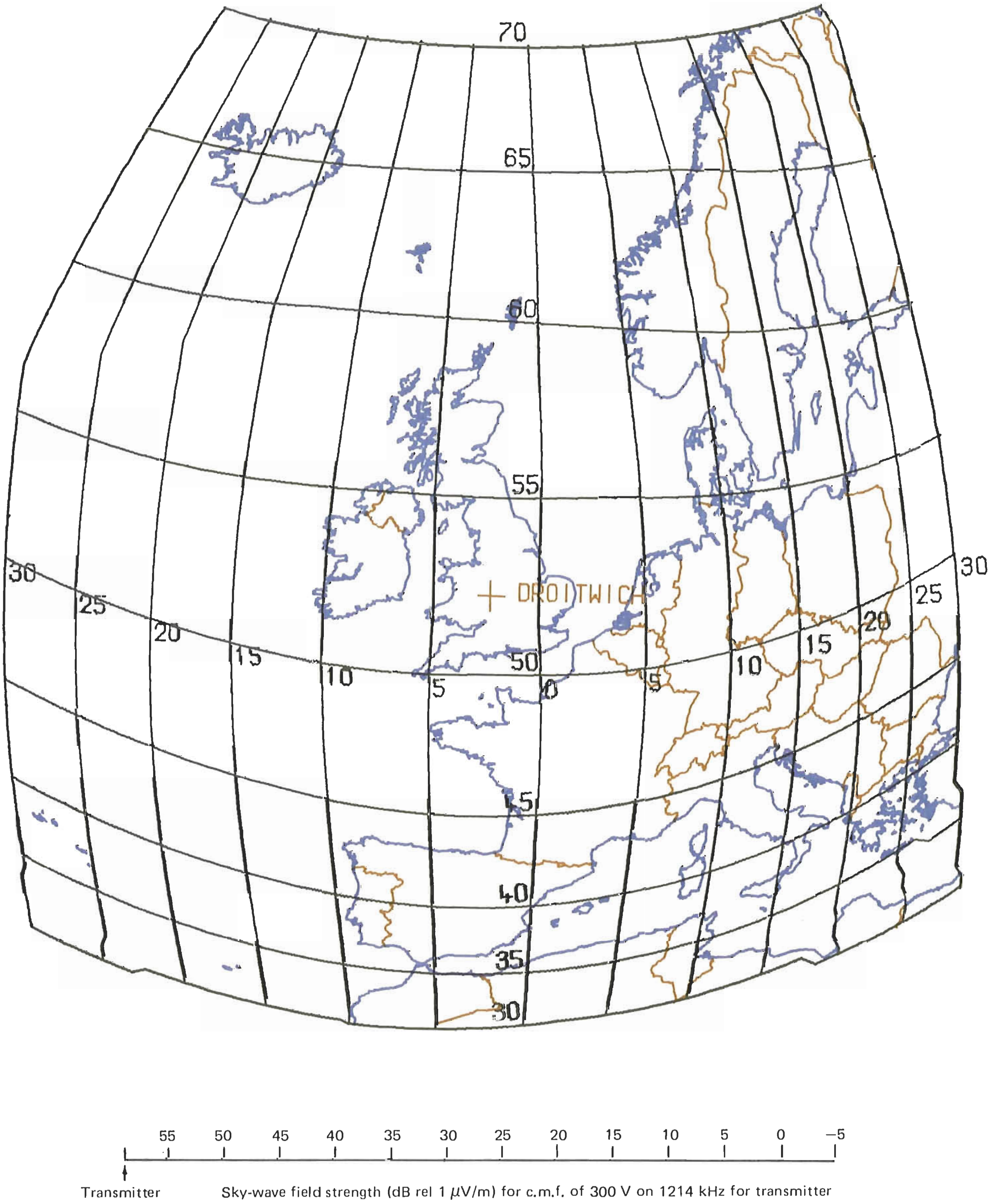


Fig. 6 - Sky-wave field strength contours

Azimuthal equi-distant projection Transmitter: Masirah
Origin: 20·6°N 58·9°E Frequency: 1410 kHz
Scale: 1/40,000,000



Sky-wave field strength (dB rel 1 μV/m) for c.m.f. of 300 V on 1214 kHz for transmitter at Droitwich

Fig. 7 - 'Field strength' map

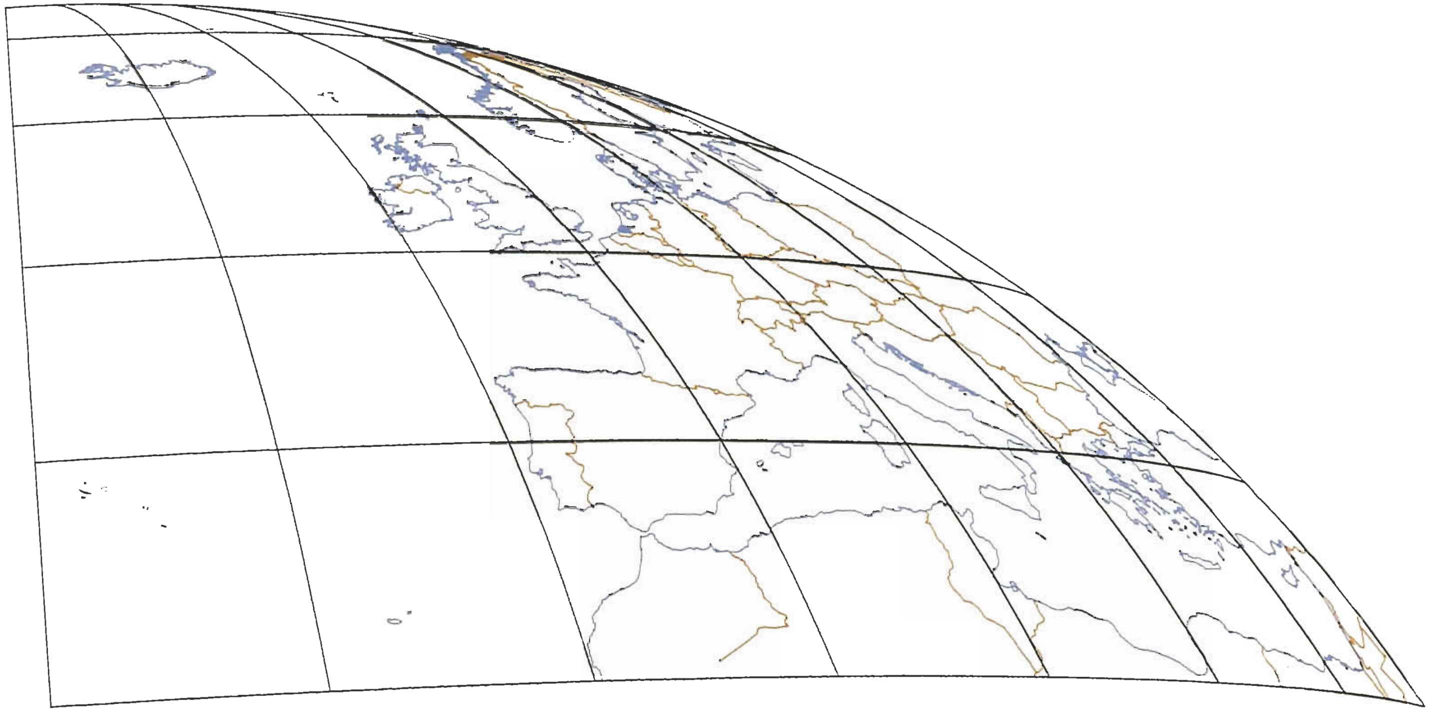


Fig. 8 - Satellite projection
Satellite longitude: 30°W
Scale: 2·5 cm represents 1° of arc subtended at the satellite

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